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ADDRESS OF THE PRESIDENT OF THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE. II

Such, then, are the facts, which call for an interpretation. More than one has been proposed; but it will be well, before discussing them, to arrive at some idea of the climate of these islands during the colder part of the Glacial epoch. Unless that were associated with very great changes in the distribution of sea and land in northern and northwestern Europe, we may assume that neither the relative position of the isotherms nor the distribution of precipitation would be very materially altered. A general fall of temperature in the northern hemisphere might so weaken the warmer ocean current from the southwest that our coasts might be approached by a cold one from the opposite direction.[35] But though these changes might diminish the difference between the temperatures of London and Leipzig, they would not make the former colder than the latter. At the present day the snow-line in the Alps on either side of the Upper Rhone Valley is not far from 8,000 feet above sea-level, and this corresponds with a temperature of about 30°. Glaciers, however, are not generally formed till about 1,000 feet higher, where the temperature is approximately 27°. Penck and Brückner place this line during the coldest part of the Ice Age at about 4,000 feet.[36]

[35] Facts relating to this subject will be found in "Climate and Time," by J. Croll, ch. II. and III., 1875. Of course the air currents would also be affected, and perhaps diminish precipitation as the latitude increased.

[36] *Loc. cit.*, p. 586, et seq. They say the snow-line, which would mean that the temperature was only 12° lower than now; but as possibly this line

In that case the temperature of the Swiss lowland would be some 15° lower than now, or near the freezing point.[37] If this fall were general, it would bring back the small glaciers on the Gran Sasso d'Italia and Monte Rotondo in Corsica; perhaps also among the higher parts of the Vosges and Schwarzwald.[38] In our own country it would give a temperature of about 35° at Carnarvon and 23° on the top of Snowdon, of 32° at Fort William and 17.5° on the top of Ben Nevis. If, in addition to this, the land were 600 feet higher than now (as it probably was, at any rate in the beginning of the glacial epoch), there would be a further drop of 2°, so that glaciers would form in the corries of Snowdon, and the region round Ben Nevis might resemble the Oetzthal Alps at the present day. This change of itself would be insufficient, and any larger drop in the ocean level would have to be continental in its effects, since we can not assume a local upheaval of much more than the above amount without seriously interfering with the river system of north central Europe. But these changes, especially the former, might indirectly diminish the abnormal warmth of winter on our northwestern coasts.[39] It is difficult to estimate the effect of this. If it did no more than place Carnarvon on the isotherm of Berlin (now lower by 2°), that would hardly bring a glacier from the Snowdonian region down to the sea. At the present time London is about 18° warmer than a place in the same latitude near the Labrador coast or the mouth of the Amur River, but the removal of that difference would involve greater changes in the distribution of sea and land than seems possible at an epoch comparatively speaking so recent. I am doubtful whether we can attribute to changed currents a reduction in British temperatures of so much as 11°; but, if we did, this would amount to 28° from all causes, and give a temperature of 20° to 22° at sea-level in England, during the coldest part of the glacial epoch.[40] That is now found, roughly speaking, in Spitzbergen, which, since its mountains rise to much the same height, should give us a general idea of the condition of Britain in the olden time.

What would then be the state of Scandinavia? Its present temperature ranges on the west coast from about 45° in the south to 35° in the north.[41] But this region must now be very much, possibly 1,800 feet, lower than it was in preglacial, perhaps also in part of glacial, times.[42] If we added 5° for this to the original 15°, and allowed so much as 18° for the diversion of the warm current, the temperature of Scandinavia would range from 7° to —3°, approximately that of Greenland northwards

might then more nearly correspond with that of glacier formation, I will provisionally accept the higher figures, especially since Corsica, the Apennines, and some other localities in Europe, seem to require a reduction of rather more than 12°.

[37] It would be 32.5° at Zurich, 31.6° at Bern, 34.1° at Geneva, about 39.0° on the plain of Piedmont and 36.0° at Lyons.

[38] See for particulars the author's "Ice Work" ("International Scientific Series"), p. 237.

[39] For much valuable information on these questions see a paper on the Climate of the Pleistocene Epoch (F. W. Harmer, *Quart. Journ. Geol. Soc.*, LVII., 1901, p. 405).

[40] The present temperature in Ireland over the zone (from south of Belfast to north of Galway Bay) which is supposed to have formed the divide of the central snowfield may be given as from 49° to 50°, nearly the same as at the sea-level in Carnarvonshire. Thus, though the district is less mountainous than Wales, it would not need a greater reduction, for the snowfall would probably be rather larger. But this reduction could hardly be less than 20°, for the glaciers would have to form nearly at the present sea-level.

[41] It is 44.42° at Bergen, 38.48° at Bodo, 35.42° at Hammerfest, 41.36° at Christiania and Stockholm.

[42] For particulars see *Geol. Mag.*, 1899, p. 97 (W. H. Hudleston) and p. 282 (T. G. Bonney).

from Upernivik. But since the difference at the present day between Cape Farewell and Christiania (the one in an abnormally cold region, the other in one correspondingly warm) is only 7°, that allowance seems much too large, while without it Scandinavia would correspond in temperature with some part of that country from south of Upernivik to north of Frederikshaab.[43] But if Christiania were not colder than Jakobshavn is now, or Britain than Spitzbergen, we are precluded from comparisons with the coasts of Baffin Bay or Victoria Land.

Thus the ice-sheet from Scandinavia would probably be much greater than those generated in Britain. It would, however, find an obstacle to progress westwards, which can not be ignored. If the bed of the North Sea became dry land, owing to a general rise of 600 feet, that would still be separated from Norway by a deep channel, extending from the Christiania Fjord round the coast northward. Even then this would be everywhere more than another 600 feet deep, and almost as wide as the Strait of Dover.[44] The ice must cross this and afterwards be forced for more than 300 miles up a slope, which, though gentle, would be in vertical height at least 600 feet. The task, if accomplished by thrust from behind, would be a heavy one, and, so far as I know, without a parallel at the present day; if the viscosity of the ice enabled it to flow, as has lately been urged,[45] we must be cautious in appealing to the great Antarctic barrier, because we now learn that more than half of it is only consolidated snow.[46] Moreover, if the ice floated across that channel, the thickness of the boulder-bearing layers would be diminished by melting (as in Ross's Barrier), and the more viscous the material, the greater the tendency for these to be left behind by the overflow of the cleaner upper layers. If, however, the whole region became dry land, the Scandinavian glaciers would descend into a broad valley, considerably more than 1,200 feet deep, which would afford them an easy path to the Arctic Ocean, so that only a lateral overflow, inconsiderable in volume, could spread itself over the western plateau.[47] An attempt to escape this difficulty has been made by assuming the existence of an independent center of distribution for ice and boulders near the middle of the North Sea bed[48] (which would demand rather exceptional conditions of temperature and precipitation); but in such case either the Scandinavian ice would be fended off from England, or the boulders, prior to its advance, must have been dropped by floating ice on the neighboring sea-floor.

If, then, our own country were but little better than Spitzbergen as a producer of ice, and Scandinavia only surpassed southern Greenland in having a rather heavier snowfall, what interpretation may we give to the glacial phenomena of Britain? Three have been proposed. One asserts that throughout the glacial epoch the British Isles generally stood at a higher level, so that the ice which almost buried them flowed out on to the beds of the North and Irish Seas. The boulder clays represent its

[43] Christiania and Cape Farewell (Greenland) are nearly on the same latitude.

[44] For details see *Geol. Mag.*, 1899, pp. 97 and 282.

[45] H. M. Deeley, *Geol. Mag.*, 1909, p. 239.

[46] E. Shackleton, "The Heart of the Antarctic," II., 277.

[47] It has indeed been affirmed (Brögger, "Om de senglaciale og postglaciale nivaforandringer i Kristianiafelted, p. 682) that at the time of the great ice-sheet of Europe the sea-bottom must have been uplifted at least 8,500 feet higher than at present. This may be a ready explanation of the occurrence of certain dead shells in deep water, but, unless extremely local, it would revolutionize the drainage system of central Europe.

[48] *Geol. Mag.*, 1901, pp. 142, 187, 284, 332.

moraines. The stratified sands and gravels were deposited in lakes formed by the rivers which were dammed up by ice-sheets.[49] A second interpretation recognizes the presence of glaciers in the mountain regions, but maintains that the land, at the outset rather above its present level, gradually sank beneath the sea, till the depth of water over the eastern coast of England was fully 500 feet, and over the western nearly 1,400 feet, from which depression it slowly recovered. By any such submergence Great Britain and Ireland would be broken up into a cluster of hilly islands, between which the tide from an extended Atlantic would sweep eastwards twice a day, its currents running strong through the narrower sounds, while movements in the reverse direction at the ebb would be much less vigorous. The third interpretation, in some respects intermediate, was first advanced by the late Professor Carvill Lewis, who held that the peculiar boulder clays and associated sands (such as those of East Anglia), which, as was then thought, were not found more than about 450 feet above the present sea-level, had been deposited in a great fresh-water lake, held up by the ice-sheets already mentioned and by an isthmus, which at that time occupied the place of the Strait of Dover. Thus, these deposits, though indirectly due to land-ice, were actually fluviatile or lacustrine. But this interpretation need not detain us, though the former existence of such lakes is still maintained, on a small scale in Britain, on a much larger one in North America, because, as was pointed out when it was first advanced, it fails to explain the numerous erratic blocks and shell-bearing sands which occur far above the margin of the hypothetical lake.

Each of the other two hypotheses involves grave difficulties. That of great confluent ice-sheets creeping over the British lowlands demands, as has been intimated, climatal conditions which are scarcely possible, and makes it hard to explain the sands and gravels, sometimes with regular alternate bedding, but more generally indicative of strong current action, which occur at various elevations to over 1,300 feet above sea-level, and seem too widespread to have been formed either beneath an ice-sheet or in lakes held up by one; for the latter, if of any size, would speedily check the velocity of influent streams. Also the mixture and crossing of boulders, which we have described, are inexplicable without the most extraordinary oscillations in the size of the contributing glaciers. To suppose that the Scandinavian ice reached to Bedfordshire and Herts and then retired in favor of north British glaciers, or vice versa, assumes an amount of variation which, so far as I am aware, is without a parallel elsewhere. So also the mixture of boulders from south Scotland, the Lake District and north Wales which lie, especially in parts of Staffordshire and Shropshire, as if dropped upon the surface, far exceeds what may reasonably be attributed to variations amplified by lateral spreading of mountain glaciers on reaching a lowland, while the frequent presence of shells in the drifts, dozens of miles away from the present coast, implies a rather improbable scooping up of the sea-bed without much injury to such fragile objects. The ice also must have been curiously inconstant in its operations. It is supposed in one place to have glided gently over its bed, in another to have gripped and torn out huge

[49] See Warren Upham, "Monogr. U. S. Geol. Survey," XXV., 1896. This explanation commends itself to the majority of British geologists as an explanation of the noted parallel roads of Glenroy, but it is premature to speak of it as "conclusively shown" (*Quart. Journ. Geol. Soc.*, LVIII., 1902, 473) until a fundamental difficulty which it presents has been discussed and removed.

masses of rock.[50] Both actions may be possible in a mountain region, but it is very difficult to understand how they could occur in a lowland or plain. Besides this we can only account for some singular aberrations of boulders, such as Shap granite well above Grosmont in Eskdale, or the Scandinavian rhomb-porphyry above Lockwood,[51] near Huddersfield, by assuming a flexibility in the lobes of an ice-sheet which it is hard to match at the present time. Again, the boulder clay of the eastern counties is crowded, as we have described, with pebbles of chalk, which generally are not of local origin, but have come from north of the Wash. Whether from the bed of a river or from a sea-beach, they are certainly water-worn. But if preglacial, the supply would be quickly exhausted, so that they would usually be confined to the lower part of the clay. As it is, though perhaps they run larger here, they abound throughout. The so-called moraines near York (supposed to have been left by a glacier retreating up that vale), those in the neighborhood of Flamborough Head and of Sheringham (regarded as relics of the North Sea ice-sheet) do not, in my opinion, show any important difference in outline from ordinary hills of sands and gravels, and their materials are wholly unlike those of any indubitable moraines that I have either seen or studied in photographs. It may be said that the British glaciers passed over very different rocks from the Alpine; but the Swiss molasse ought to have supplied abundant sand, and the older interglacial gravels quantities of pebbles; yet the differences between the morainic materials on the flank of the Jura or near the town of Geneva and those close to the foot of the Alps are varietal rather than specific.

Some authorities, however, attribute such magnitude to the ice-sheets radiating from Scandinavia that they depict them, at the time of maximum extension, as not only traversing the North Sea bed and trespassing upon the coast of England, but also radiating southward to overwhelm Denmark and Holland, to invade northern Germany and Poland, to obliterate Hanover, Berlin and Warsaw, and to stop but little short of Dresden and Cracow, while burying Russia on the east to within no great distance of the Volga and on the south to the neighborhood of Kief. Their presence, however, so far as I can ascertain, is inferred from evidence[52] very similar to that which we have discussed in the British lowlands. That Scandinavia was at one time almost wholly buried beneath snow and ice is indubitable; it is equally so that at the outset the land stood above its present level, and that during the later stages of the glacial epoch parts, at any rate of southern Norway, had sunk down to a maximum depth of 800 feet. In Germany, however, erratics are scattered over its plain and stranded on the slopes of the Harz and Riesengebirge up to about 1,400 feet above sea-level. The glacial drifts of the lowlands sometimes contain dislodged masses of neighboring rocks like those at Cromer, and we read of other indications of ice action. I must, however, observe that since the glacial deposits of Möen, Warnemünde and Rügen often present not only close resemblances to those of our eastern counties but also very similar difficulties, it is not permissible to quote the one in support

[50] That this has occurred at Cromer is a very dubious hypothesis (see *Geol. Mag.*, 1905, pp. 397, 524). The curious relations of the drift and chalk in the islands of Möen and Rügen are sometimes supposed to prove the same action. Knowing both well, I have no hesitation in saying that the chalk there is, as a rule, as much in situ as it is in the Isle of Wight.

[51] About half-way across England and 810 feet above sea-level. P. F. Kendall, *Quart. Journ. Geol. Soc.*, LVIII., 1902, p. 498.

[52] A valuable summary of it is given in "The Great Ice Age," J. Geikie, ch. XXIX., XXX., 1894.

of the other, seeing that the origin of each is equally dubious. Given a sufficient "head" of ice in northern regions, it might be possible to transfer the remains of organisms from the bed of the Irish Sea to Moel Tryfaen, Macclesfield and Gloppa; but at the last-named, if not at the others, we must assume the existence of steadily alternating currents in the lakes in order to explain the corresponding bedding of the deposit. This, however, is not the only difficulty. The "Irish Sea glacier" is supposed to have been composed of streams from Ireland, southwest Scotland and the Lake District, of which the second furnished the dominant contingent; the first-named not producing any direct effect on the western coast of Great Britain, and the third being made to feel its inferiority and "shouldered in upon the mainland." But even if this ever happened, ought not the Welsh ice to have joined issue with the invaders a good many miles to the north of its own coast?[53] Welsh boulders at any rate are common near the summit of Moel Tryfaen, and I have no hesitation in saying that the pebbles of riebeckite-rock, far from rare in its drifts, come from Mynydd Mawr, hardly half a league to the east-southeast, and not from Ailsa Craig.[54]

As such frequent appeal is made to the superior volume of the ice-sheet which poured from the Northern Hills over the bed of the Irish Sea, I will compare in more detail the ice-producing capacities of the several districts. The present temperature of west central Scotland may be taken as 47°; its surface as averaging about 2,500 feet, rising occasionally to nearly 4,000 feet above sea-level. In the western part of the southern uplands the temperature is a degree higher, and the average for altitude at most not above 1,500 feet. In the Lake District and the northern Pennines the temperature is increased by another degree, and the heights are, for the one 1,800 feet with a maximum of 3,162 feet, for the other 1,200 feet and 2,892 feet. In north Wales the temperature is 50°, the average height perhaps 2,000 feet, and the culminating point 3,571 feet. For the purpose of comparing the ice-producing powers of these districts we may bring them to one temperature by adding 300 feet to the height for each degree below that of the Welsh region. This would raise the average elevation of central and southern Scotland to 3,400 feet and 2,100 feet, respectively; for the Lake District and northern Pennines to 2,100 feet and 1,500 feet. We may picture to ourselves what this would mean, if the snow-line were at the sea-level in north Wales, by imagining 8,000 feet added to its height and comparing it with the Alps. North Wales would then resemble a part of that chain which had an average height of about 10,000 feet above sea-level, and culminated in a peak of 11,571 feet; the Lake District would hardly differ from it; the northern Pennines would be like a range of about 9,000 feet, its highest peak being 11,192 feet. Southern Scotland would be much the same in average height

[53] From Moel Tryfaen to the nearest point of Scotland is well over a hundred miles, and it is a few less than this distance from Gloppa to the Lake District. In order to allow the Irish Sea ice-sheet to reach the top of Moel Tryfaen the glacier productive power of Snowdonia has been minimized (Wright, "Man and the Glacial Epoch," pp. 171, 172). But the difference between that and the Arenig region is not great enough to make the one incompetent to protect its own borderland while the other could send an ice-sheet which could almost cover the Clent Hills and reach the neighborhood of Birmingham. Anglesey also, if we suppose a slight elevation and a temperature of 29° at the sea-level, would become a center of ice-distribution and an advance guard to North Wales.

[54] The boulders of picrite near North Nobla, from Llanerchymedd, though they have traveled southward, have moved away much to the west.

as the first and second, and would rise, though rarely, to above 11,000 feet; the average in central Scotland would be about 11,400 feet, and the maximum about 13,000 feet. Thus, north Wales, the Lake District and the southern uplands would differ little in ice-productive power; while central Scotland would distinctly exceed them, but not more than the group around the Finsteraarhorn does that giving birth to the Rhone glacier. In one respect, however, all these districts would differ from the Alps —that, at 8,000 feet, the surface, instead of being furrowed with valleys, small and great, would be a gently shelving plateau, which would favor the formation of piedmont glaciers. Still, unless we assume the present distribution of rainfall to be completely altered (for which I do not know any reason), the relative magnitudes of the ice coming from these centers (whether separate glaciers or confluent sheets) could differ but little. Scotch ice would not appreciably "shoulder inland" that from the Lake District, nor would the Welsh ice be imprisoned within its own valleys.

During the last few years, however, the lake-hypothesis of Carvil Lewis has been revived under a rather different form by some English advocates of land-ice. For instance, the former presence of ice-dammed lakes is supposed to be indicated in the upper parts of the Cleveland Hills by certain overflow channels. I may be allowed to observe that, though this view is the outcome of much acute observation and reasoning,[55] it is wholly dependent upon the ice-barriers already mentioned, and that if they dissolve before the dry light of sceptical criticism, the lakes will "leave not a rack behind." I must also confess that to my eyes the so-called "overflow channels" much more closely resemble the remnants of ancient valley-systems, formed by only moderately rapid rivers, which have been isolated by the trespass of younger and more energetic streams, and they suggest that the main features of this picturesque upland were developed before rather than after the beginning of the glacial epoch. I think that even "Lake Pickering," though it has become an accepted fact with several geologists of high repute, can be more simply explained as a two-branched "valley of strike," formed on the Kimeridge clay, the eastern arm of which was beheaded, even in preglacial times, by the sea.[56] As to Lake Oxford,[57] I must confess myself still more sceptical. Some changes no doubt have occurred in later glacial and postglacial times; valleys have been here raised by deposit, there deepened sometimes by as much as 100 feet; the courses of lowland rivers may occasionally have been altered; but I doubt whether, since those times began, either ice-sheet or lake has ever concealed the site of that university city.

The submergence hypothesis assumes that, at the beginning of the glacial epoch, our islands stood rather above their present level, and during it gradually subsided, on the west to a greater extent than on the east, till at last the movement was reversed, and they returned nearly to their former position. During most of this time glaciers came down to the sea from the more mountainous islands, and in winter an ice-foot formed upon the shore. This, on becoming detached, carried away boulders, beach pebbles and finer detritus. Great quantities of the last also were swept by swollen streams into the estuaries and spread over the sea-bed by coast currents, settling down

[55] P. F. Kendall, *Quart. Journ. Geol. Soc.*, LVIII., 1902, 471.

[56] See for instance the courses of the Medway and the Beult over the Weald clay (C. Le Neve Foster and W. Topley, *Quart. Journ. Geol. Soc.*, XXI., 1865, p. 443).

[57] F. W. Harmer, *Quart. Journ. Geol. Soc.*, LXIII., 1907, p. 470.

especially in the quiet depths of submerged valleys. Shore-ice in Arctic regions, as Colonel H. W. Feilden[58] has described, can striate stones and even the rock beneath it, and is able, on a subsiding area, gradually to push boulders up to a higher level. In fact the state of the British region in those ages would not have been unlike that still existing near the coasts of the Barents and Kara Seas. Over the submerged region southward, and in some cases more or less eastward, currents would be prevalent; though changes of wind[59] would often affect the drift of the floating ice-rafts. But though the submergence hypothesis is obviously free from the serious difficulties which have been indicated in discussing the other one, it gives a simple explanation of the presence of marine organisms, and accords with what can be proved to have occurred in Norway, Weigatz Island, Novaia Zemlya, on the Lower St. Lawrence, in Grinnell Land and elsewhere,[60] it undoubtedly involves others. One of them—the absence of shore terraces, caves or other sea marks—is perhaps hardly so grave as it is often thought to be. It may be met by the remark that unless the glacial age lasted for a very long time and the movements were interrupted by well-marked pauses, we could not expect to find any such record. In regard also to another objection, the rather rare and sporadic occurrence of marine shells, the answer would be that, on the Norway coast, where the ice-worn rock has certainly been submerged, sea-shells are far from common and occur sporadically in the raised deltaic deposits of the fjords.[61]

An advocate of this view might also complain, not without justice, that, if he cited an inland terrace, it was promptly dismissed as the product of an ice-dammed lake, and his frequent instances of marine shells in stratified drifts were declared to have been transported from the sea by the lobe of an ice-sheet; even if they have been carried across the path of the Arenig ice, more than forty miles, as the crow flies, from the Irish Sea up the Valley of the Severn, or forced some 1,300 feet up Moel Tryfaen.[62] The difficulty in the latter case, he would observe is not met by saying the ice-sheet would be able to climb that hill "given there were a sufficient head behind it."[63] That ice can be driven uphill has long been known, but the existence of the "sufficient head" must be demonstrated, not assumed. There may be "no logical halting-place between an uplift of ten or twenty feet to surmount a *roche moutonnée* and an equally gradual elevation to the height of Moel Tryfaen," yet there is a common-sense limitation, even to a destructive *sorites*. The argument, in fact, is more specious than valid, till we are

[58] *Quart. Journ. Geol. Soc.*, XXXIV., 1878, p. 556.

[59] See p. 23, and for the currents now dominant consult Dr. H. Bassett in Professor Herdman's Report on the Lancashire Sea Fisheries, *Trans. Biol. Soc. Liverpool*, XXIV., 1910, p. 123.

[60] See "Ice Work," p. 221, and *Geol. Mag.*, 1900, p. 289.

[61] If, as seems probable, the temperature was changing rather rapidly the old fauna would be pauperized and the new one make its way but slowly into the British fjords.

[62] Critics of the submergence hypothesis seem to find a difficulty in admitting downward and upward movements, amounting sometimes to nearly 1,400 feet during Pleistocene ages; but in the northern part of America the upheaval, at any rate, has amounted to about 1,000 feet, while on the western coast, beneath the lofty summit of Mount St. Elias, marine shells of existing species have been obtained some 5,000 feet above sea-level. It is also admitted that in several places the preglacial surface of the land was much above its present level. On the Red River, whatever be the explanation, foraminifers, radiolarians and sponge spicules have been found at 700 feet above sea-level, and near Victoria, on the Saskatchewan, even up to about 1,900 feet.

[63] P. F. Kendall in Wright's "Man and the Glacial Period," p. 171.

told approximately how thick the northern ice must be to produce the requisite pressure, and whether such an accumulation would be possible. The advocates of land ice admit that, before it had covered more than a few leagues on its southward journey its thickness was less than 2,000 feet, and we are not entitled, as I have endeavored to show, to pile up ice indefinitely on either our British highlands or the adjacent sea-bed. The same reason also forbids us largely to augment the thickness of the latter by the snowfall on its surface, as happens to the Antarctic barrier ice. Even if the thickness of the ice-cap over the Dumfries and Kirkcudbright hills had been about 2,500 feet, that, with every allowance for viscosity, would hardly give us a head sufficient to force a layer of ice from the level of the sea-bed to a height of nearly 1,400 feet above it and at a distance of more than 100 miles.

Neither can we obtain much support from the instance in Spitzbergen, described by Professors Garwood and Gregory, where the Ivory Glacier, after crossing the bed of a valley, had transported marine shells and drift from the floor (little above sea-level) to a height of about 400 feet on the opposite slope. Here the valley was narrow, and the glacier had descended from an inland ice-reservoir, much of which was at least 2,800 feet above the sea, and rose occasionally more than a thousand feet higher.[64]

But other difficulties are far more grave. The thickness of the chalky boulder clay alone, as has been stated, not unfrequently exceeds 100 feet, and, though often much less, may have been reduced by denudation. This is an enormous amount to have been transported and distributed by floating ice. The materials also are not much more easily accounted for by this than by the other hypothesis. A continuous supply of well-worn chalk pebbles might indeed be kept up from a gradually rising or sinking beach, but it is difficult to see how, until the land had subsided for at least 200 feet, the chalky boulder clay could be deposited in some of the East Anglian valleys or on the Leicestershire hills. That depression, however, would seriously diminish the area of exposed chalk in Lincolnshire and Yorkshire, and the double of it would almost drown that rock. Again, the East Anglian boulder clay, as we have said, frequently abounds in fragments and finer detritus from the Kimeridge and Oxford clays. But a large part of their outcrop would disappear before the former submergence was completed. Yet the materials of the boulder clay, though changing as it is traced across the country, more especially from east to west, seem to vary little in a vertical direction. The instances, also, of the transportation of boulders and smaller stones to higher levels, sometimes large in amount, as in the transference of "brockram" from outcrops near the bed of the Eden valley to the level of Stainmoor Gap, seem to be too numerous to be readily explained by the uplifting action of shore-ice in a subsiding area. Such a process is possible, but we should anticipate it would be rather exceptional.

Submergence also readily accounts for the above-named sands and gravels, but not quite so easily for their occurrence at such very different levels. On the eastern side of England gravelly sands may be found beneath the chalky boulder clay from well below sea-level to three or four hundred feet above it. Again, since, on the submergence hypothesis, the lower boulder clay about the estuaries of the Dee and the Mersey must represent a deposit from piedmont ice in a shallow sea, the mid-glacial sand (sometimes not very clearly marked in this part) ought not to be more than

[64] *Quart. Journ. Geol. Soc.*, LIV., 1898, p. 205. Earlier observations of some upthrust of materials by a glacier are noted on p. 219.

forty or fifty feet above the present Ordnance datum. But at Manchester it reaches over 200 feet, while near Heywood it is at least 425 feet. In other words, the sands and gravels, presumably (often certainly) mid-glacial, mantle, like the upper boulder clay, over great irregularities of the surface, and are sometimes found, as already stated, up to more than 1,200 feet. Either of these deposits may have followed the sea-line upwards or downwards, but that explanation would almost compel us to suppose that the sand was deposited during the submergence and the upper clay during the emergence; so that, with the former material, the higher in position is the newer in time, and with the latter the reverse. We must not, however, forget that in the island of Rügen we find more than one example of a stratified gravelly sand between two beds of boulder clay (containing Scandinavian erratics) which present some resemblance to the boulder clays of eastern England, while certain glacial deposits at Warnemünde, on the Baltic coast, sometimes remind us of the Contorted Drift of Norfolk.

Towards the close of the glacial epoch, the deposition of the boulder clay ceased[65] and its denudation began. On the low plateaus of the eastern counties it is often succeeded by coarse gravels, largely composed of flint, more or less water-worn. These occasionally include small intercalations of boulder clay, have evidently been derived from it, and indicate movement by fairly strong currents. Similar gravels are found overlying the boulder clay in other parts of England, sometimes at greater heights above sea-level. Occasionally the two are intimately related. For instance, a pit on the broad, almost level, top of the Gogmagog Hills, about 200 feet above sea-level, and four miles south of Cambridge, shows a current-bedded sand and gravel, overlain by a boulder clay, obviously rearranged; while other pits in the immediate neighborhood expose varieties and mixtures of one or the other material. But, as true boulder clay occurs in the valley below, these gravels must have been deposited, and that by rather strong currents, on a hill-top—a thing which seems impossible under anything like the existing conditions; and, even if the lowland were buried beneath ice full 200 feet in thickness, which made the hill-top into the bed of a lake, it is difficult to understand how the waters of that could be in rapid motion. Rearranged boulder clays also occur on the slopes of valleys[66] which may be explained, with perhaps some of the curious sections near Sudbury, by the slipping of materials from a higher position. But at Old Oswestry gravels with indications of ice action are found at the foot of the hills almost 700 feet below those of Gloppa.

Often the plateau gravels are followed at a lower level by terrace gravels,[67] which descend towards the existing rivers, and suggest that valleys have been sometimes deepened, sometimes only reexcavated. The latter gravels are obviously deposited by rivers larger and stronger than those which now wind their way seawards, but it is difficult to explain the former gravels by any fluviatile action, whether the water from a melting ice-sheet ran over the land or into a lake, held up by some temporary barrier. But the sorting action of currents in a slowly shallowing sea would be quite competent to account for them, so they afford an indirect support to the hypothesis

[65] Probably deposits of a distinctly glacial origin (such as those near Hessle in Yorkshire) continued in the northern districts, but on these we need not linger.

[66] For instance, at Stanningfield in the valley of the Lark.

[67] These contain the instruments worked by paleolithic (Acheulean) man who, in this country at any rate, is later than the chalky boulder clay.

of submergence. It is, however, generally admitted that there have been oscillations both of level and of climate since any boulder clay was deposited in the district south of the Humber and the Ribble. The passing of the great ice age was not sudden, and glaciers may have lingered in our mountain regions when paleolithic man hunted the mammoth in the valley of the Thames, or frequented the caves of Devon and Mendip. But of these times of transition before written history became possible, and of sundry interesting topics connected with the ice age itself—of its cause, date and duration, whether it was persistent or interrupted by warmer episodes, and, if so, by what number, of how often it had already recurred in the history of the earth —I must, for obvious reasons, refrain from speaking, and content myself with having endeavored to place before you the facts of which, in my opinion, we must take account in reconstructing the physical geography of western Europe, and especially of our own country, during the age of ice.

Not unnaturally you will expect a decision in favor of one or the other litigant after this long summing up. But I can only say that, in regard to the British Isles, the difficulties in either hypothesis appear so great that, while I consider those in the "land-ice" hypothesis to be the more serious, I can not as yet declare the other one to be satisfactorily established, and think we shall be wiser in working on in the hope of clearing up some of the perplexities. I may add that, for these purposes, regions like the northern coasts of Russia and Siberia appear to me more promising than those in closer proximity to the north or south magnetic poles. This may seem a "lame and impotent conclusion" to so long a disquisition, but there are stages in the development of a scientific idea when the best service we can do it is by attempting to separate facts from fancies, by demanding that difficulties should be frankly faced instead of being severely ignored, by insisting that the giving of a name can not convert the imaginary into the real, and by remembering that if hypotheses yet on their trial are treated as axioms, the result will often bring disaster, like building a tower on a foundation of sand. To scrutinize, rather than to advocate any hypothesis, has been my aim throughout this address, and, if my efforts have been to some extent successful, I trust to be forgiven, though I may have trespassed on your patience and disappointed a legitimate expectation.

T. G. BONNEY

THE FERTILITY OF THE SOIL[1]

I BELIEVE it is customary for any one who has the honor of presiding over a section of the British Association to provide in his presidential address either a review of the current progress of his subject or an account of some large piece of investigation by which he himself has illuminated it. I wish I had anything of the latter kind which I could consider worthy to occupy your attention for the time at my disposal; and as to a review of the subject, I am not without hopes that the sectional meetings themselves will provide all that is necessary in the way of a general review of what is going forward in our department of science. I have, therefore, chosen instead to deal from an historic point of view with the opinions which have prevailed about one central fact, and I propose to set before you this morning an account of the ebb and flow of ideas as to the causes of the fertility of the soil, a question which has naturally occupied the attention

[1] Address by the chairman of the Agricultural Sub-section of the British Association for the Advancement of Science, Sheffield, 1910.